

Ultra-High Flux project: X-ray/THz Source based on Asymmetric Dual Axis Energy Recovery Configuration

I.V. Konoplev, A. Seryi

JAI, Oxford, UK

G. Burt

Cockcroft Institute, Lancaster, UK

R. Ainsworth

FNAL, USA

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Evolution of computers and light sources



"IBM bringing out a personal computer would be like teaching an elephant to tap dance" cca. 1981

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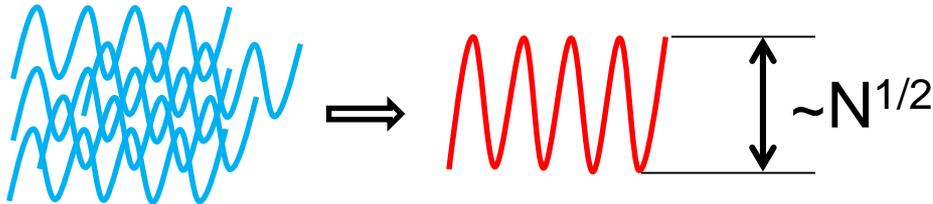
1K or 2K RAM AVAILABLE!

IMMEDIATE DELIVERY

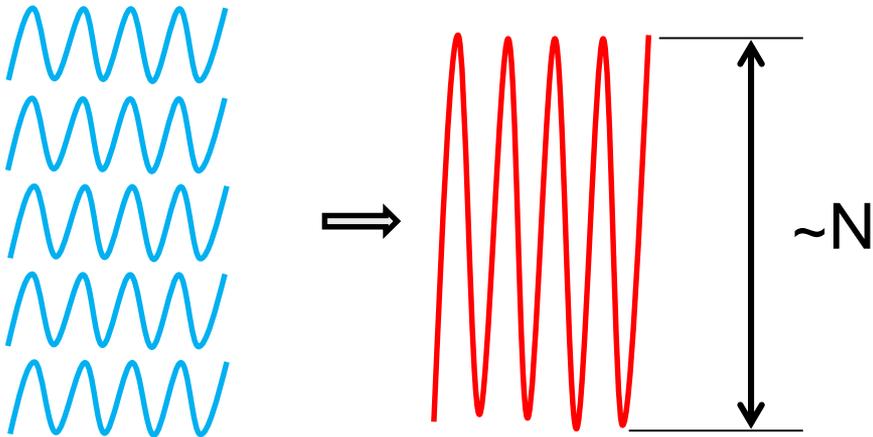
The unique



3rd generation => 4th generation



3rd generation SR sources:
the electrons emit photons with
random phases



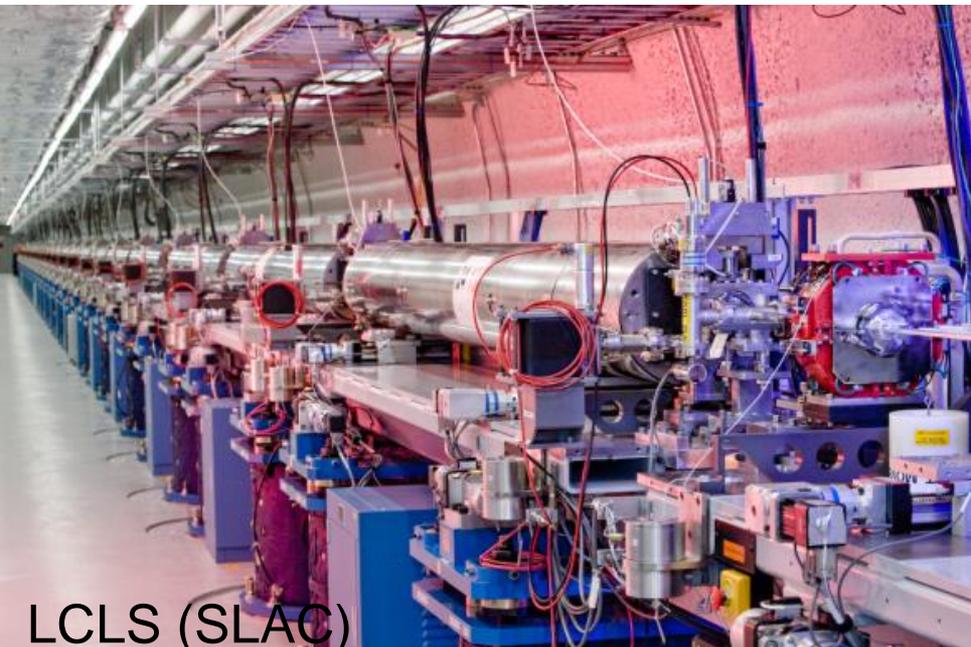
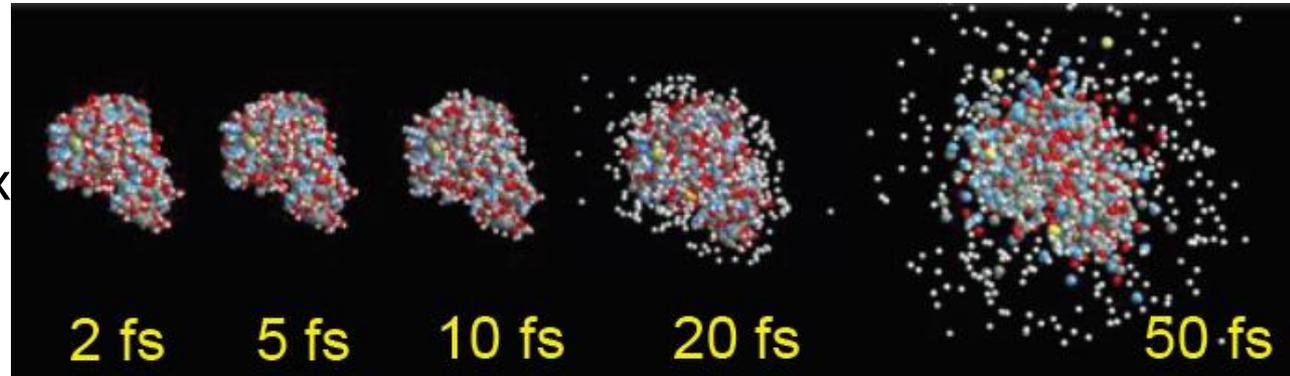
4th generation SR sources:
the electrons emit photons
all as one

4th generation sources – Free Electron Lasers (FELs)

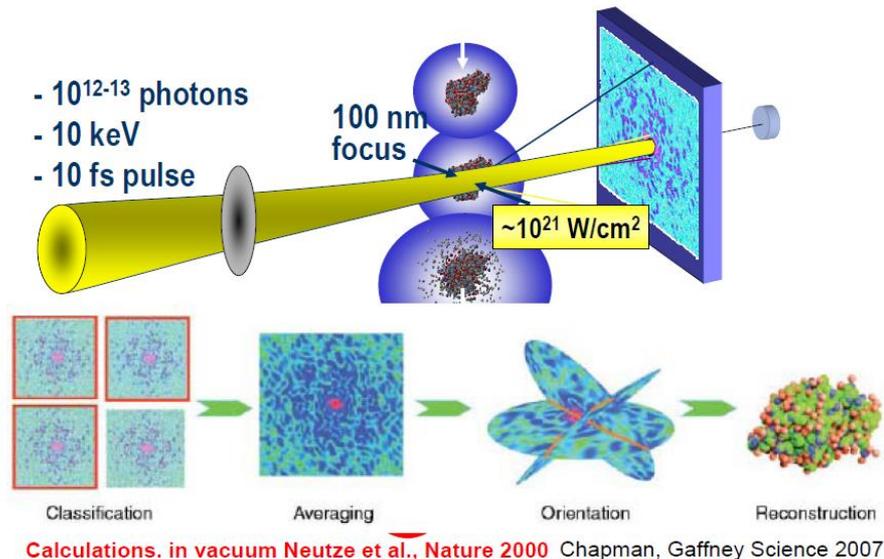
FEL brightness is 10 orders of magnitude higher than brightness of 3rd generation sources

4th generation - FEL at Stanford

Immense brightness -
analysis of very complex
molecules (proteins)

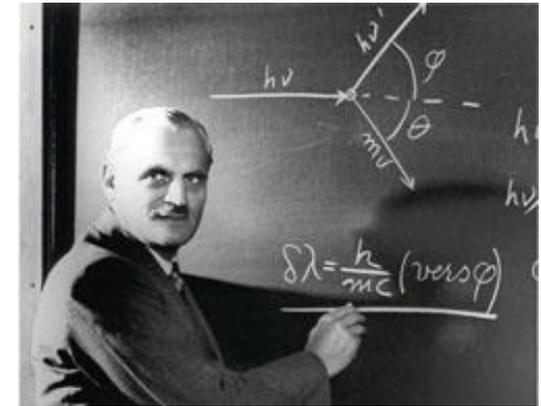
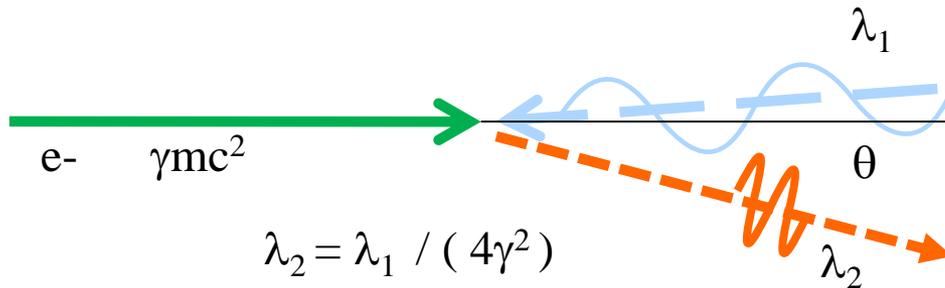


LCLS (SLAC)



Compton light sources

Based on the reflection of photons from accelerated electrons with an energy transfer to photons



Arthur Compton

Compact X-ray light source

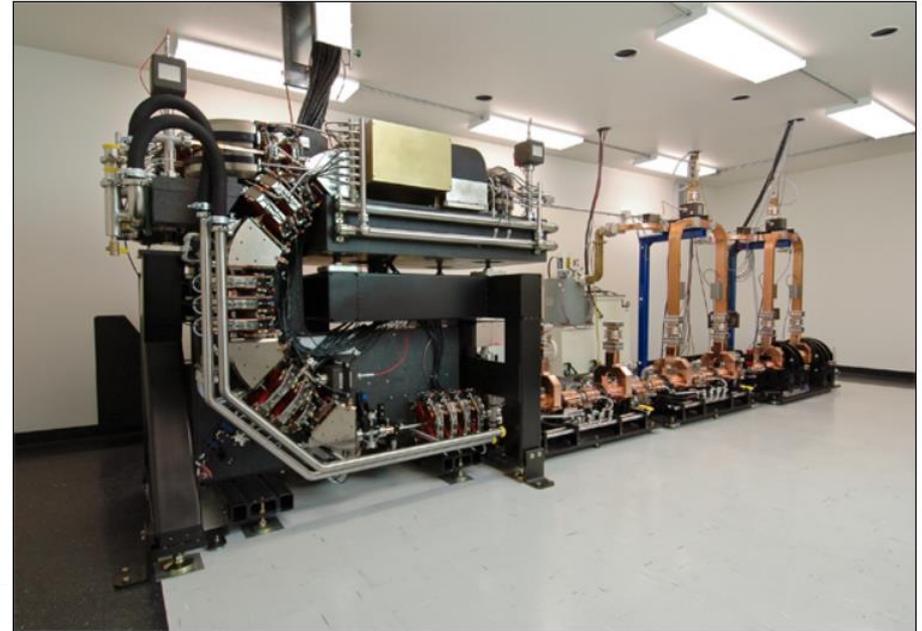
- 25 MeV accelerator
- X-ray tuneable from a few keV up to 35 keV

Commercially available, e.g.:
Lyncean Technologies, Inc.

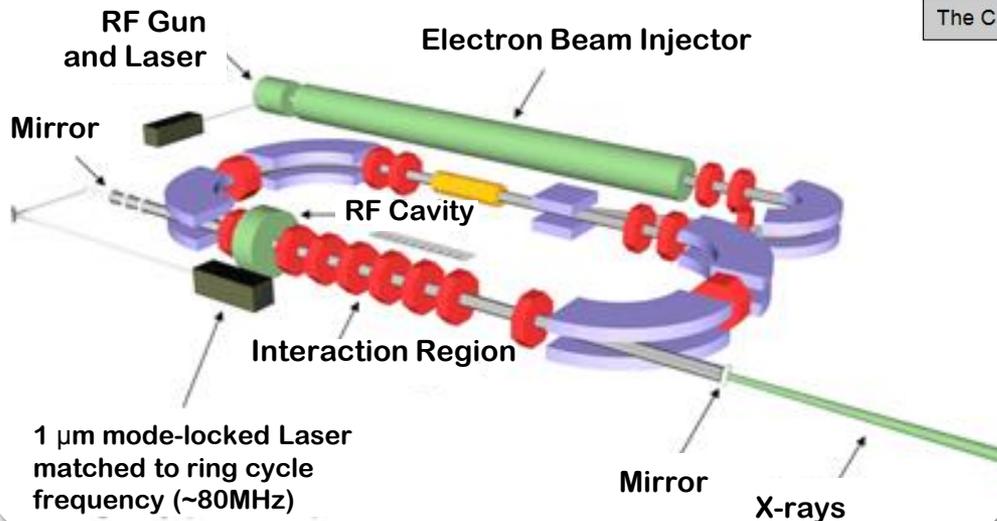
Compact X-ray light source

25 MeV accelerator
X-ray tuneable from a few keV up to
35 keV

Fits in a 10x25 ft room



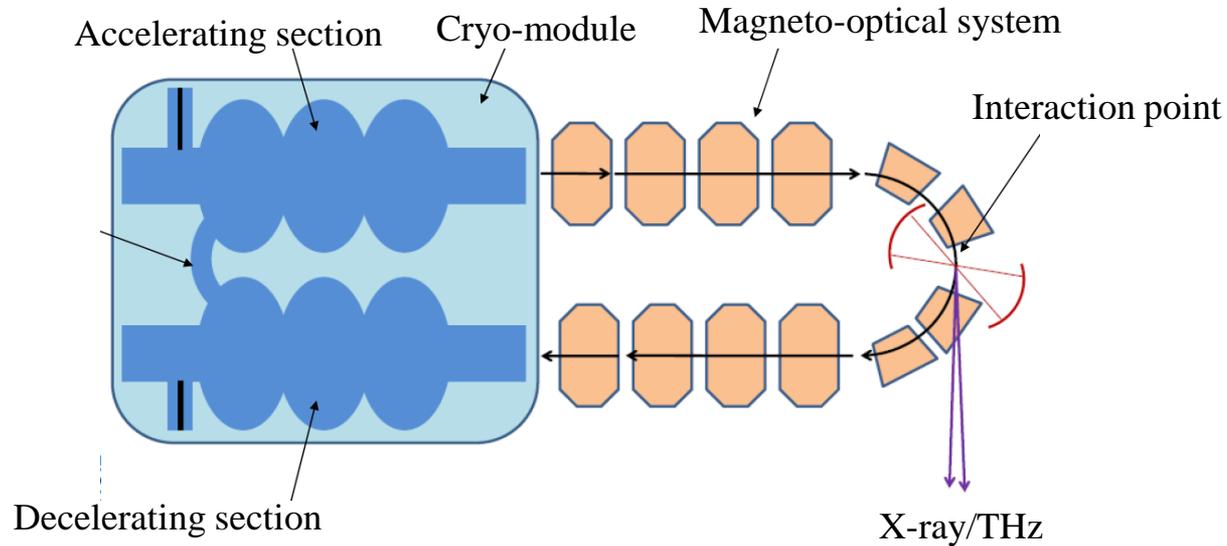
The CLS assembled at the headquarters of Lyncean Technologies, Inc. in Palo Alto, CA



RF power source outside (not on the photo)

<http://www.lynceantech.com/index.html>

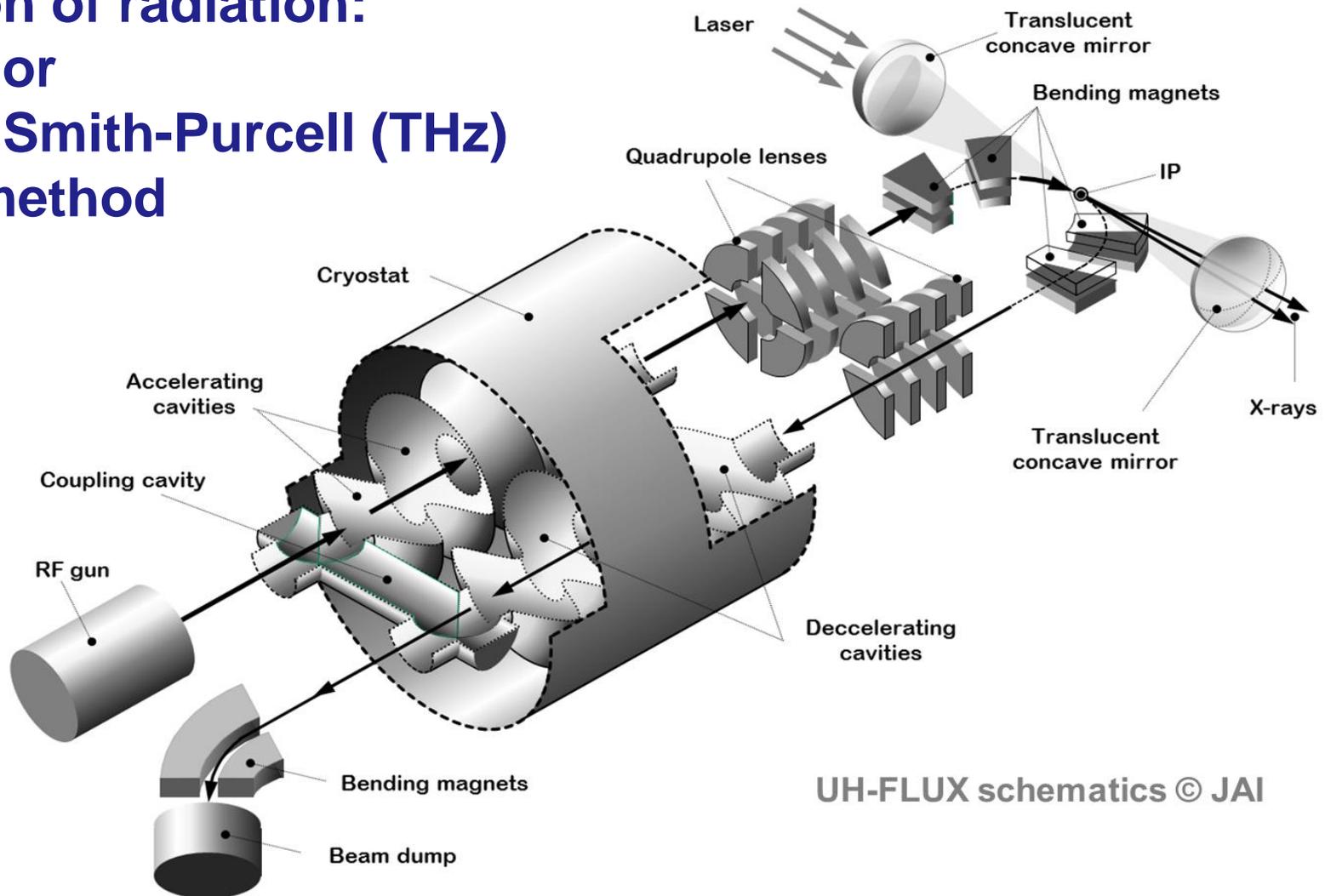
Next steps in Compton/THz sources – UH-FLUX project



- **Collaboration of UK centers JAI, CI, STFC and UK industry is developing an advanced Compton/THz source**
- [1] International (PCT) Patent Application No. PCT/GB2012/052632 (WO2013/061051) filed on the 26th October 2012
- [2] Oxford University Isis Project No. 11330 – “Asymmetric superconducting RF structure” (UK Priority patent application 1420936.5 titled ‘Asymmetric superconducting RF structure’ filed on the 25th November 2014

UH-FLUX – conceptual layout

**Generation of radiation:
Compton or
Coherent Smith-Purcell (THz)
or other method**

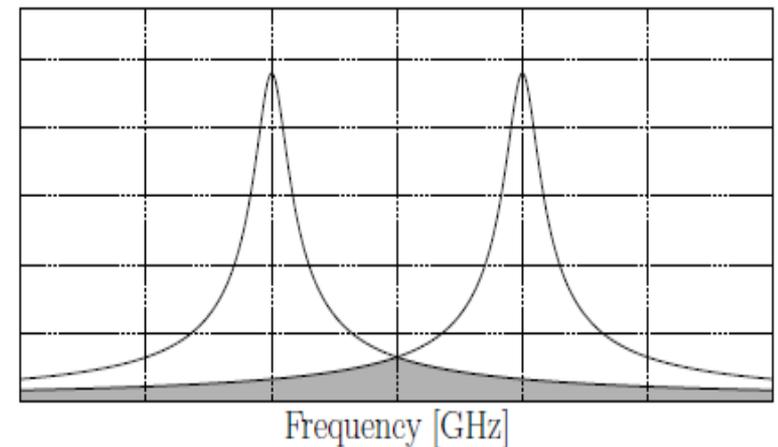
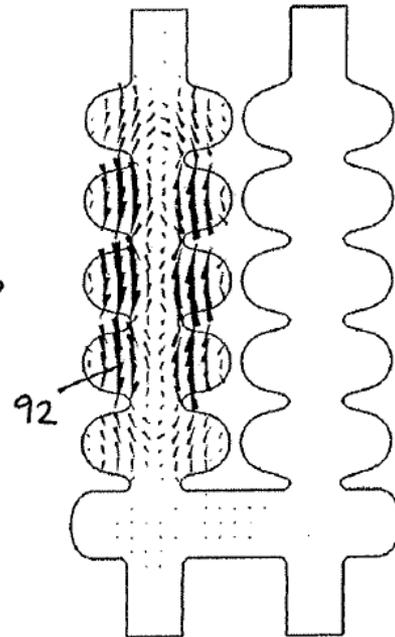
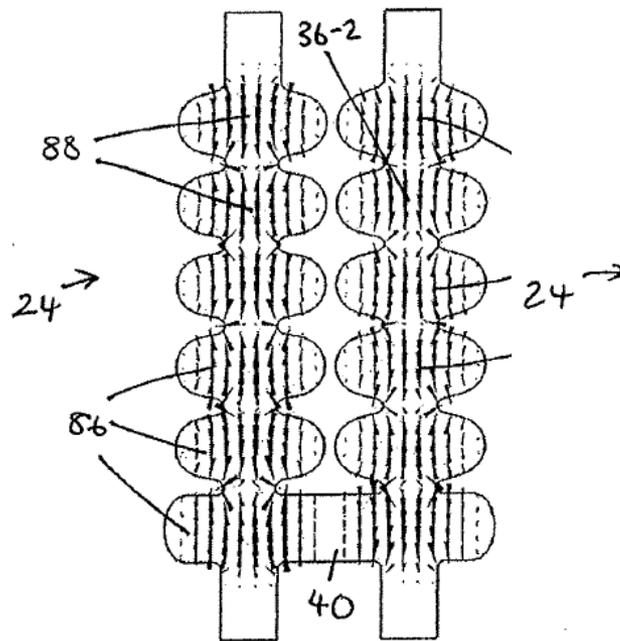


UH-FLUX: Asymmetric ERL

Decoupling all modes except the accelerating mode to maximize the beam current

Acc. mode

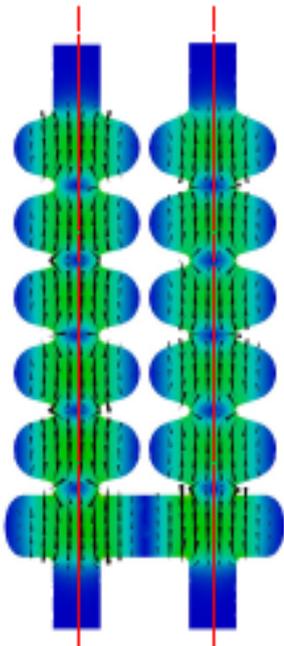
One of transverse modes



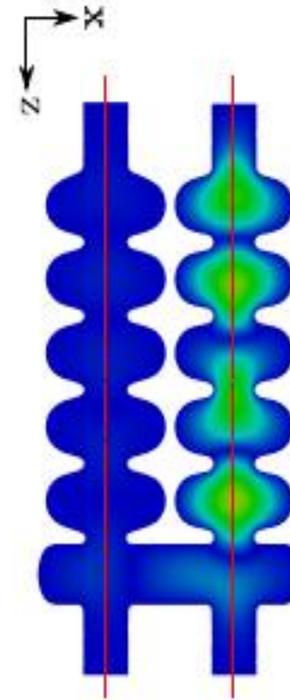
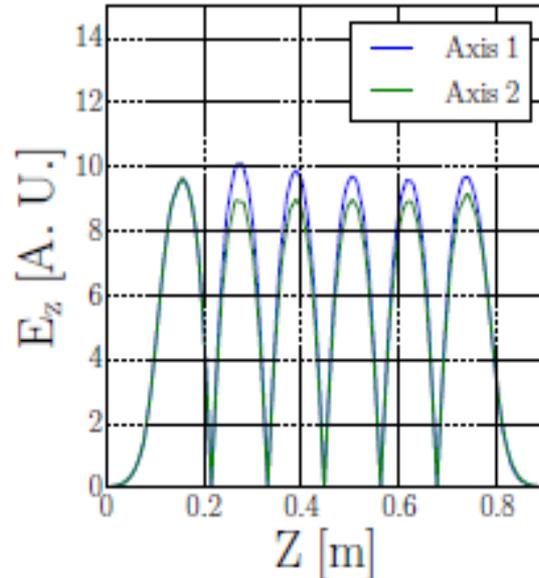
UH-FLUX: Asymmetric ERL

Electric field contour plot of operating eigenmode at 1.3GHz

Axis 1 Axis 2

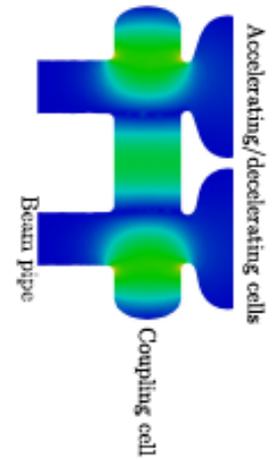


Operating field flatness @1.3GHz



Electric field contour plot of dipole eigenmode at 1.73GHz

Electric field contour plot of resonant coupler eigenmode at 1.48GHz



UH-FLUX: Asymmetric ERL

$$\Delta r \cong -\frac{2c}{\omega} \nabla_{\perp} V(r, \varphi) \frac{L}{W} \mathbf{R}_{12} \quad \text{Electron bunch deviation from designed trajectory due to HOM}$$

$$\Delta \tau \cong \frac{1}{2} \left(\frac{\mathbf{R}_{12} \theta}{S_0} \right)^2 T_g = \frac{\Delta r}{2S_0} \frac{\Delta r}{c} \quad \text{Time detuning of the electron bunch due to HOM}$$

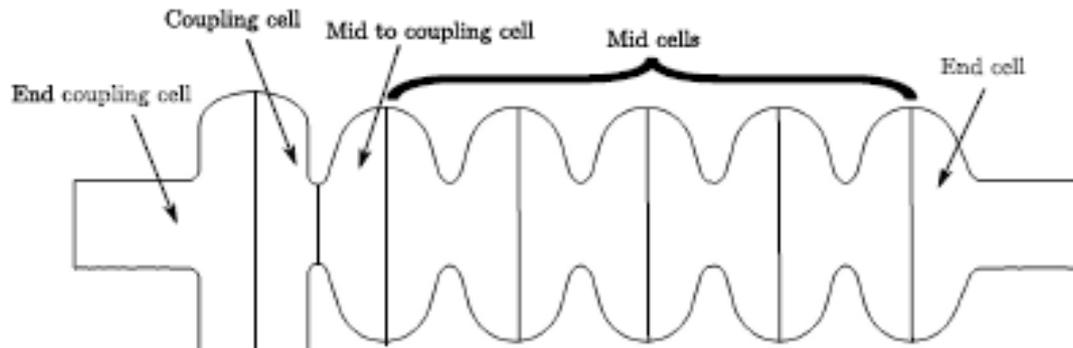
$$\Delta \phi \cong \frac{(\mathbf{R}_{12} \theta) \Delta r}{S_0 \lambda_0} \pi \quad \text{Phase detuning of the electron bunch due to HOM}$$

$$I_{max} = (D_2 W \omega) / (2r K_m F^{\infty}) \quad \text{Maximum electron beam current above which beam transportation will be interrupted due to HOM}$$

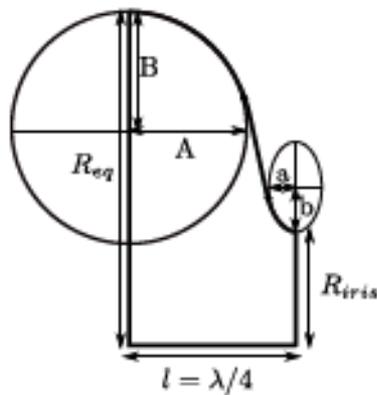
$$F^{\infty} = \frac{\sin(\delta \omega_n T_{rep})}{2 \cosh(T_{rep}/T_{dec}) - \cos(\delta \omega_n T_{rep})}$$

$$|V_2| = \left| V_1 e^{-T_{rep}/T_{dec}} \right| \quad K_m = c/4 [R/Q]_j^m$$

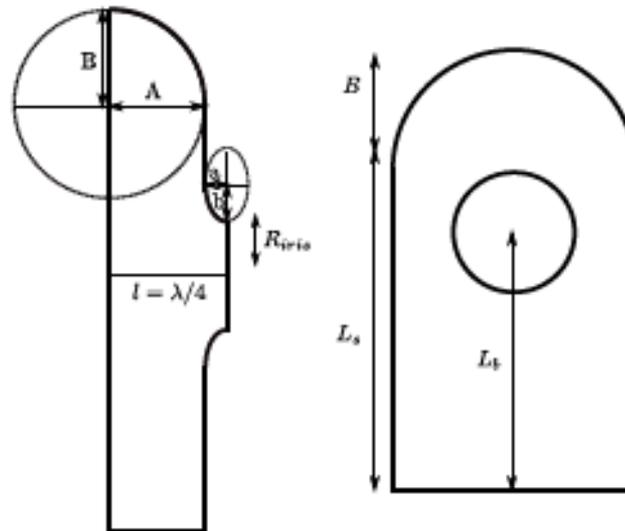
Technical drawing



Midcell



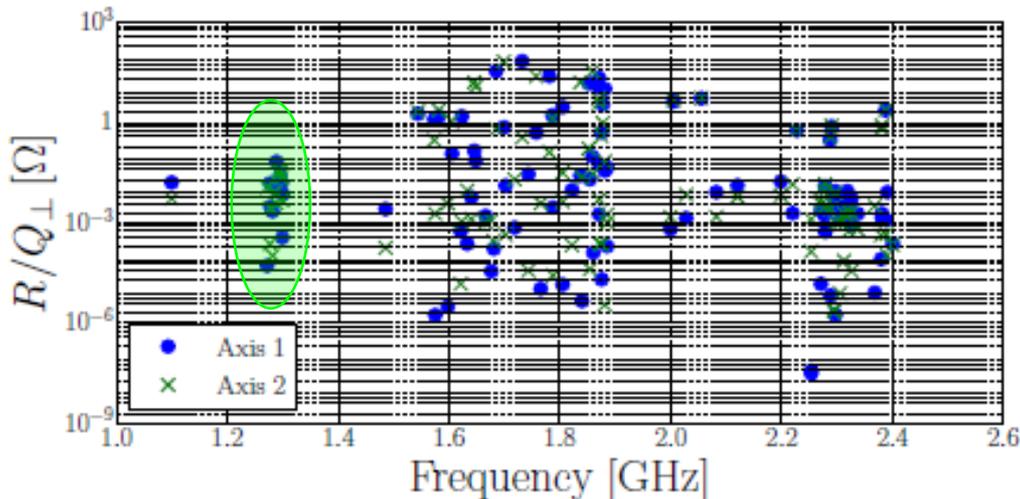
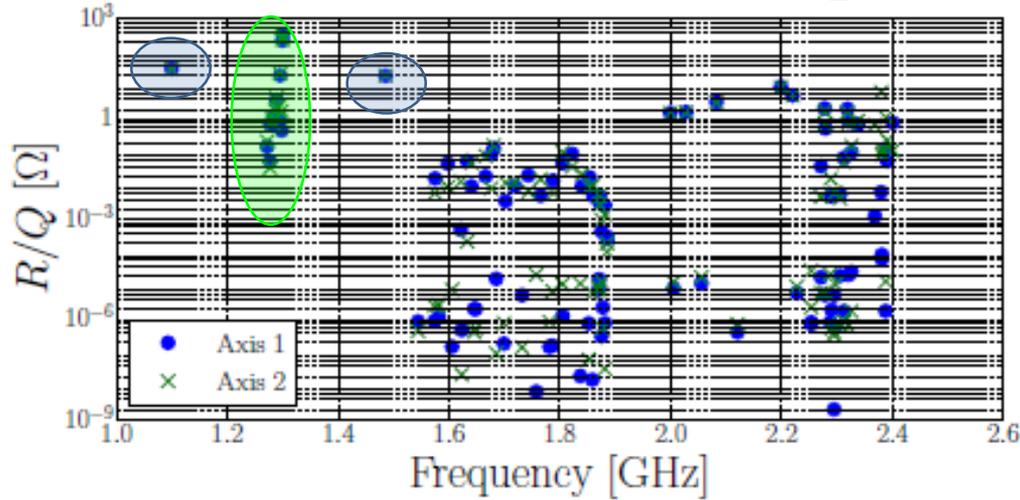
Coupling cell



| Parameter | Axis 1 cell [mm] | Axis 2 cell [mm] |
|-----------------------|------------------|------------------|
| Mid cells | | |
| R_{eq} | 103.3 | 103.3 |
| A | 42 | 42 |
| B | 42 | 43.1 |
| R_{iris} | 35.75 | 37 |
| a | 12.75 | 11.75 |
| b | 18 | 20 |
| l | 57.7 | 57.7 |
| End cells | | |
| R_{eq} | 103.3 | 104.3 |
| A | 42 | 42 |
| B | 42 | 43 |
| R_{iris} | 39 | 39 |
| a | 12.75 | 11.75 |
| b | 18 | 20 |
| l | 58.54 | 60.96 |
| Mid to coupling cells | | |
| R_{eq} | 103.3 | 104.3 |
| A | 42 | 42 |
| B | 43.4 | 43.5 |
| R_{iris} | 35 | 35 |
| a | 12.75 | 9.69 |
| b | 18 | 20 |
| l | 57.7 | 57.7 |
| Coupling cells | | |
| A | 48.052 | 48.052 |
| B | 29 | 29 |
| R_{iris} | 35 | 35 |
| a | 9.6 | 9.6 |
| b | 10.152 | 10.152 |
| l | 57.652 | 57.652 |
| L_s | 150 | 150 |
| L_b | 111 | 111 |
| End coupling cells | | |
| A | 47.5 | 47.5 |
| B | 29.76 | 29.76 |
| R_{iris} | 39 | 39 |
| a | 9.945 | 9.945 |
| b | 9.945 | 9.945 |
| l | 57.652 | 57.652 |
| L_s | 150 | 150 |
| L_b | 111 | 111 |

Table of numerical model parameters

First 100 eigenmodes R/Q and R_{\perp}/Q



| Frequency GHz | Axis 1 R/Q Ω | Axis 2 R/Q | Axis 1 $R/Q_{\perp,x}$ Ω | Axis 2 $R/Q_{\perp,x}$ | Axis 1 $R/Q_{\perp,y}$ Ω | Axis 2 $R/Q_{\perp,y}$ |
|-------------------------|-----------------------------|-----------------|---------------------------------------|---------------------------|---------------------------------------|---------------------------|
| Highest R/Q | | | | | | |
| 1.3 | 348.71 | 301.51 | 0.0675 | 0.0365 | 0.0074 | 0.0 |
| 1.29943 | 231.71 | 247.59 | 0.0014 | 0.0059 | 0.0003 | 0.0048 |
| 1.09966 | 32.622 | 32.367 | 9.5769 | 9.0660 | 0.0166 | 0.0055 |
| 1.29532 | 21.075 | 23.878 | 0.0014 | 0.0267 | 0.0281 | 0.0333 |
| 1.48554 | 20.337 | 20.429 | 12.094 | 12.360 | 0.0026 | 0.0001 |
| Highest $R/Q_{\perp,x}$ | | | | | | |
| 1.70216 | 0.0035 | 0.0127 | 65.207 | 0.8680 | 0.0134 | 0.0004 |
| 1.74343 | 0.0211 | 0.0069 | 61.997 | 0.4792 | 0.0294 | 3.8679 |
| 1.87193 | 0.0050 | 0.0029 | 35.500 | 0.0810 | 0.0555 | 0.0002 |
| 1.85436 | 0.0181 | 0.0091 | 17.329 | 0.3260 | 0.0208 | 4.2119 |
| 1.48554 | 20.337 | 20.429 | 12.094 | 12.360 | 0.0026 | 0.0001 |
| Highest $R/Q_{\perp,y}$ | | | | | | |
| 1.73192 | 5.4419 | 1.4736 | 0.0005 | 0.0001 | 72.089 | 0.3764 |
| 1.68526 | 1.6890 | 9.9178 | 0.0024 | 1.8274 | 36.312 | 0.6537 |
| 1.78142 | 1.5499 | 8.7076 | 0.0039 | 0.0070 | 25.636 | 0.1329 |
| 1.87103 | 1.6368 | 7.9211 | 4.8525 | 0.0037 | 22.491 | 4.0005 |
| 1.8523 | 7.7902 | 6.4131 | 0.0033 | 0.0001 | 15.388 | 0.1740 |

$$R/Q_n = \frac{|V_{\parallel,n}(0)|^2}{\omega_n U_n} \quad R/Q_{\perp,n} = \frac{|V_{\perp,n}(x)|^2}{\omega_n U_n}$$

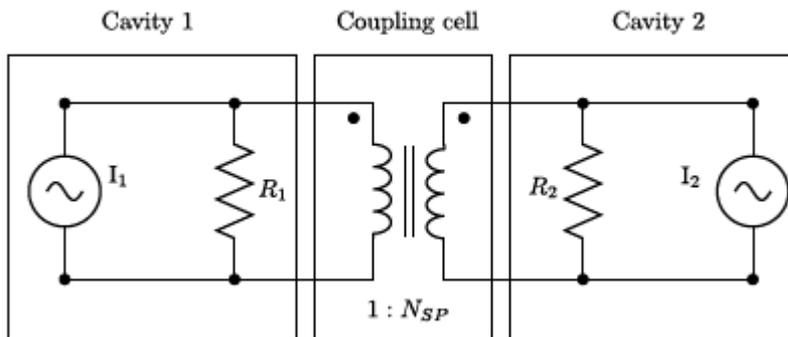
$$V_{\parallel,n}(x) = \int_{-\infty}^{\infty} E_{z,n}(x,z) e^{i\omega_n z/c} dz$$

$$V_{\perp,n} = i \frac{c}{\omega_n x} [V_{\parallel,n}(x) - V_{\parallel,n}(0)]$$

The R_{\perp}/Q calculated @ 1mm from the axis

Maximize the BBU start current allowing to transport up to 2A beam without break-up

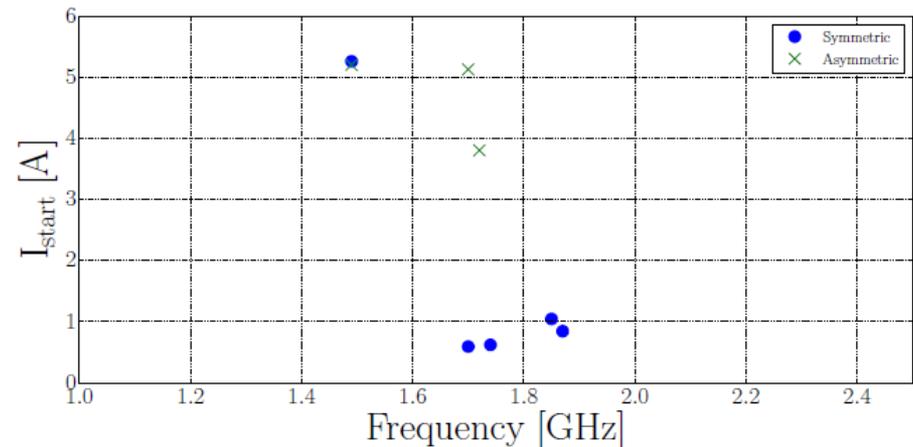
Schematic of RLC diagram of dual axis structure



$$I_{asymmetric} > \frac{(1 + N_{SP}^2) I_{symmetric}}{2N_{SP}}$$

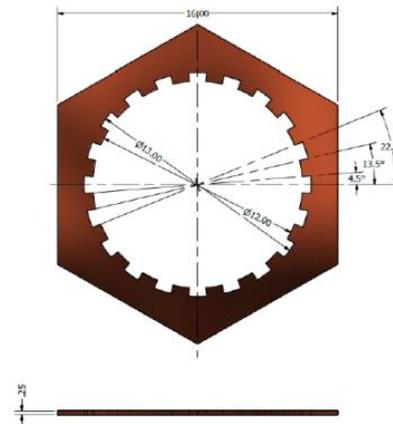
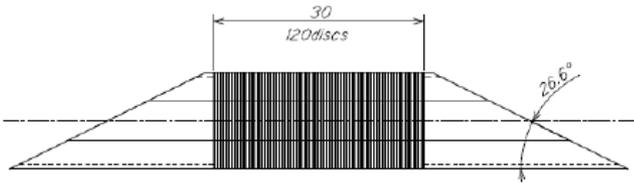
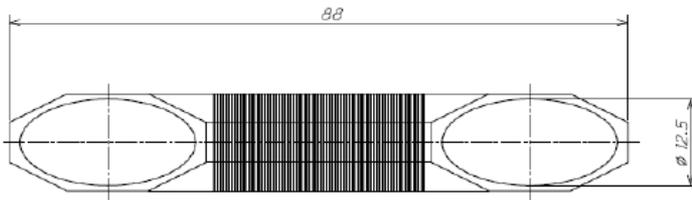
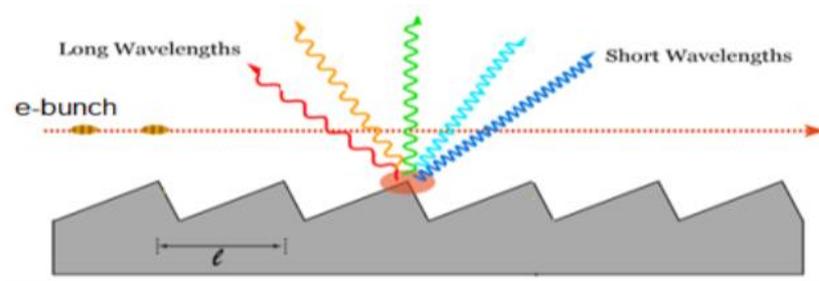
N_{SP} is the voltage transformer ratio

HOMs start currents

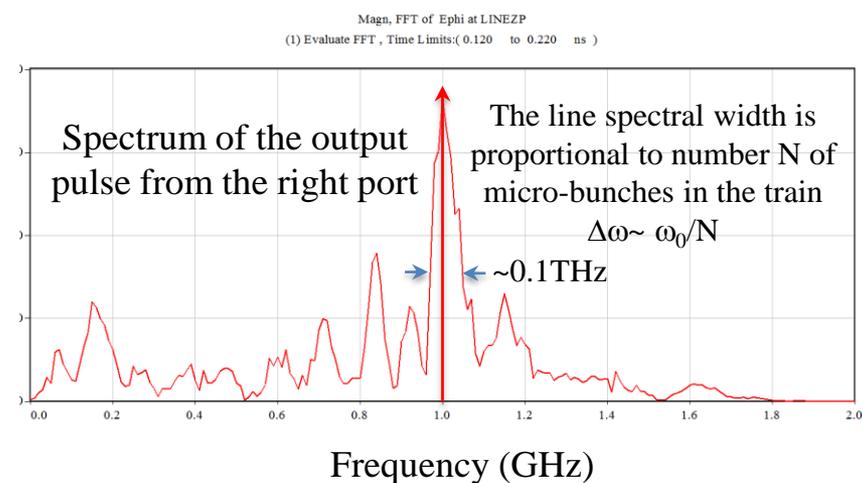
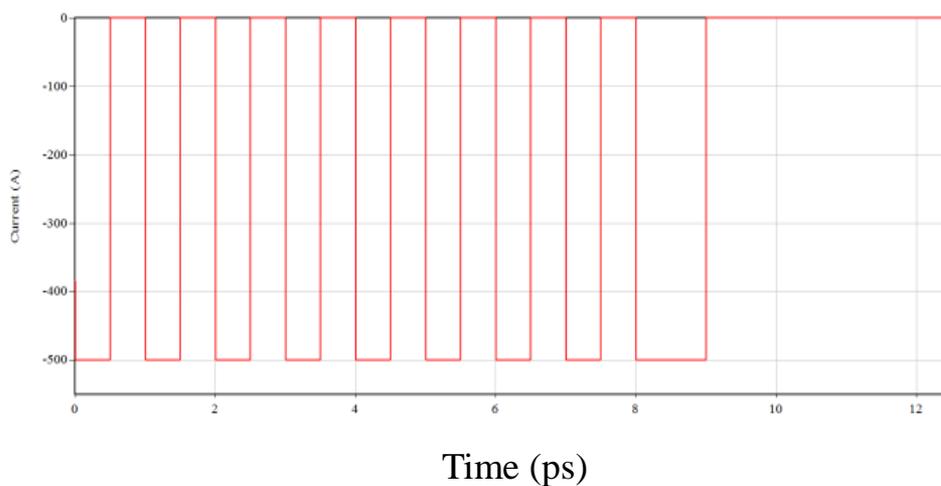
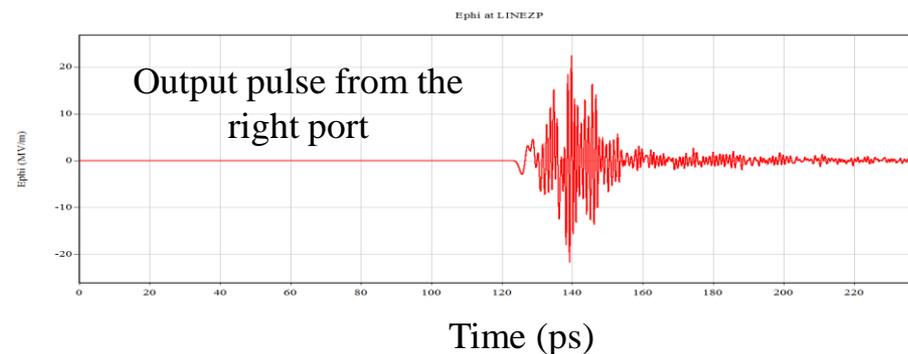
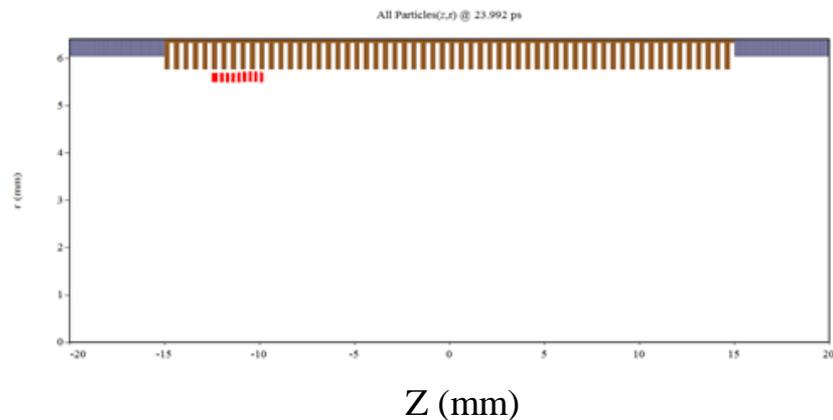


The smallest current is above 3.8A for the AERL configuration

UH-FLUX –THz Coherent Smith-Purcell



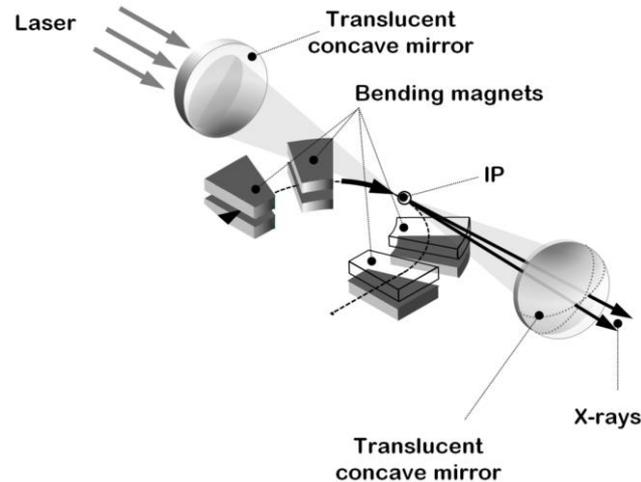
UH-FLUX –THz Coherent Smith-Purcell



9 Micro-bunches were generated

UH-FLUX – X-ray

Compton source



1/ The peak brightness $\sim 10^{23} - 10^{24}$ photons / (mm² × mrad² × s × 0.1% bandwidth)

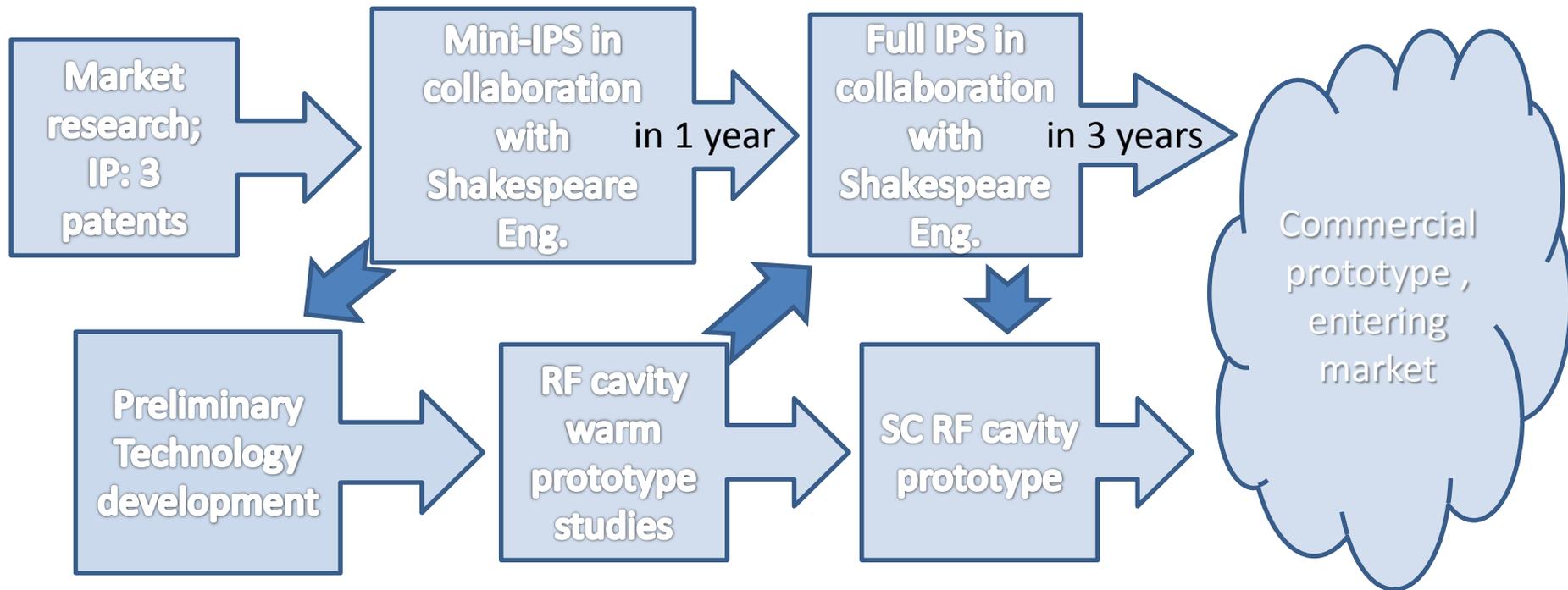
2/ X-ray flux $\sim 9 \times 10^{12} - 3 \times 10^{13}$ photons/second inside a 0.1% bandwidth

3/ Average brightness $\sim 10^{14}$ photons / (mm² × mrad² × s × 0.1% bandwidth)

at 15keV photons for 20MeV beam

We are studying the range of possible applications of UH-FLUX technology, including medical direction

UH-FLUX: Asymmetric Energy Recovery Linac – Next steps



1/ PCT international patent application PCT/GB2012/052632 titled 'X-ray Generation' filed on the 24th October 2012.

2/ PCT/GB2013/053101 titled 'Distributed electron beam collector' filed on the 25th November 2013.

3/ UK Priority patent application 1420936.5 titled 'Asymmetric superconducting RF structure' filed on the 25th November 2014.

Summary

UH Flux: X-ray/THz compact SCRF AERL Light Source

- Based on novel dual axis asymmetric cavity energy-recovery system
- Energy-recovery SCRF system = increased efficiency
- Asymmetric structure = high current (>1A)
- High current = high flux of THz or X-ray photons
- New distributed electron beam collector – to reduce impact of high current electron beam

Thank you